Ensemble Methods for Coastal Ocean Flows

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LONG-TERM GOALS

The long-terms goals of this research are to improve our ability to understand and predict environmental conditions in the coastal ocean.

OBJECTIVES

The central objective of the proposed research is to explore problems in coastal ocean modeling, including ensemble forecasting, Lagrangian trajectory analysis, and the utility of Lyapunov vectors for dynamical analysis and ensemble prediction of coastal ocean flows. The research will be conducted by an incoming graduate student, in collaboration with the PI.

APPROACH

The proposed research will extend previous work on these topics by directly addressing issues in coastal ocean modeling, including ensemble forecasting, Lagrangian motion, and the utility of Lyapunov vectors for ensemble-based analysis and prediction of coastal ocean flows. The research is being carried out primarily by a graduate student, with assistance from and guidance by the PI. The details of the graduate student research project are dependent in part on the specific interests of the student, but will proceed along the following general lines.

The ensemble prediction problem for the coastal ocean, with the important element of strong forcing by atmospheric circulations that have their own intrinsic predictability limits, will be explored. Recent work by the PI and collaborators has focused on understanding the characteristics of instabilities and disturbance growth in the coastal ocean and in idealized models with relevance to the coastal ocean. The use of Lyapunov vectors, computed by the new method of Wolfe and Samelson (2007a), as a basis for ensemble generation in the presence of flow-dependent instabilities will be explored.

The effect of disturbance growth and other error sources for models of the coastal ocean is an additional component of this problem that deserves further attention. Ensemble statistics analyzed in current work by Kim et al. (2009a, 2009b) show that ensemble variance in the dynamical variables is

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associated with topographic obstacles, and with uncertainty in wind forcing, initial conditions, and open boundary conditions, and give initial estimates of the relative amplitudes of these effects.

In general, appropriate ensemble methods for the coastal ocean will need to include representations both of atmospheric uncertainty and of oceanic uncertainty. A natural approach to consider is a multi-ensemble system, in which a set of ocean simulation ensembles is constructed, each of which is forced by a member of an atmospheric ensemble. Because the size of such a system will grow rapidly, however, other approaches may prove more efficient. For example, the atmospheric forcing may be considered part of the ocean model, and model-error schemes may be used to represent the uncertainty in the forcing, through parameterized stochasticity or other modifications to the forcing fields.

The ensemble forecast approach leads naturally to consideration of ensemble Kalman filters in the related context of data assimilation (Evensen, 1994). Ensemble Kalman filters offer several potential advantages over competing assimilation methods (Hamill and Snyder, 2000; Snyder and Zhang, 2003; Hamill, 2006). They are related to the error subspace statistical estimation techniques advocated by Lermusiaux and Robinson (1999) and Lermusiaux (2007). Versions of the ensemble Kalman filter have been implemented in global ocean models (Keppenne, 2000). Techniques for implementation of ensemble Kalman filter schemes in limited-area models have been developed for regional atmospheric models (Torn et al., 2006; Dirren et al., 2007), and these should be readily adaptable for regional ocean modeling. These methods are ripe for exploration in the context of recent and ongoing studies of data assimilation in coastal ocean models at COAS (Oke et al., 2002; Kurapov et al., 2005a, 2005b), and the pilot Oregon coastal ocean forecasting system (http://agate.coas.oregonstate.edu/ocs_index.html) developed at COAS by Kurapov, Egbert, and the PI with support from the NOAA-OSU Cooperative Institute for Oceanographic Satellite Studies.

Related topics that may be explored, both directly and in the ensemble context, are the characteristics and statistics of Lagrangian trajectories in the coastal ocean. Extensions of the idealized studies of Kuebel Cervantes et al. (2004) and Kuebel et al. (2003) to simulations with full three-dimensional variability and realistic topography representative of the U.S. west coast would be of considerable interest, and could have important implications for understanding of regional biological and other related shelf processes. In general, little is currently known regarding the predictive information content for Lagrangian motion that can be derived from ensembles of Eulerian simulations for wind-driven coastal ocean flows, and investigations in this direction would be likely to yield interesting new insights as well.

WORK COMPLETED

The graduate student completed the first year of coursework in the COAS Physical Oceanography program and has successfully passed the discipline comprehensive exam, thereby qualifying for and officially entering the Ph.D. program. The first part of the thesis work, completed during summer 2009, focused on gaining experience with numerical models for simulation of coastal ocean circulation, including both a curvilinear coordinate and an unstructured grid model.

RESULTS

The graduate student entered the graduate program in Fall 2008, and no new research results are available yet.

RELATED PROJECTS

The planned work is related to the ONR NOPP project ‘Boundary Conditions, Data Assimilation, and Predictability in Coastal Ocean Models’ (ONR Award Number N00014-05-1-0891).

REFERENCES

Dirren, S., R. Torn, and G. Hakim, 2007. A Data Assimilation Case Study Using a Limited-Area Ensemble Kalman Filter. Monthly Weather Review, 135(4), 1455–1473, DOI: 10.1175/MWR3358.1

Evensen, G., 1994: Sequential data assimilation with a nonlinear quasi-geostrophic model using Monte Carlo methods to forecast error statistics *J. Geophys. Res.*, **99,** 10 143–10 162.

Hamill, T., 2006. Ensemble-based atmospheric data assimilation. In: *Predictability of Weather and Climate*, ed. Tim Palmer and Renate Hagedorn. Cambridge University Press 2006.

Hamill, T. M., and C. Snyder, 2000. A Hybrid Ensemble Kalman Filter–3D Variational Analysis Scheme. Monthly Weather, 128, 2905–2919.

Keppenne C. L., 2000. Data assimilation into a primitive equation model using a parallel ensemble Kalman filter. *Mon. Wea. Rev.*, **128**, 1971-1981, 2000.

Kim, S., R. M. Samelson, and C. Snyder, 2009a. Ensemble-based estimates of the predictability of wind-driven coastal ocean flow over topography. Monthly Weather Review, in press.

Kim, S., C. Snyder, and R. M. Samelson, 2009b. Toward an uncertainty budget for a coastal ocean model. Manuscript in preparation.

Kuebel Cervantes, B. T., J. S. Allen, and R. M. Samelson, 2004. Lagrangian characteristics of continental shelf flows forced by periodic wind stress. *Nonlinear Processes in Geophysics*, 11, 3-16.

Kuebel, B. T., J. S. Allen, and R. M. Samelson, 2003. A modeling study of Eulerian and Lagrangian aspects of shelf circulation off Duck, North Carolina. *Journal of Physical Oceanography*, 33, 2070-2092.

Kurapov, A.L., J. S. Allen, G.D. Egbert, R.N. Miller, P.M. Kosro, M. Levine, and T. Boyd, 2005a. Distant effect of assimilation of moored ADP currents into a model of coastal wind-driven circulation off Oregon, *J.Geophys. Res.*, **110**, C02022, doi:10.1029/2003JC002195.

Kurapov, A.L., J.S. Allen, G.D. Egbert, R.N. Miller, P.M. Kosro, M.D. Levine, T. Boyd, J.A. Barth, and J.N. Moum, 2005b, Assimilation of moored velocity data in a model of coastal wind-driven circulation off Oregon: multivariate capabilities, *J. Geophys. Res.,*

Lermusiaux, P.F.J. and A.R. Robinson., 1999. Data Assimilation via Error Subspace Statistical Estimation, Part I: Theory and Schemes (.pdf). Monthly Weather Review, Vol. 127(8), 1385-1407.

Lermusiaux P.F.J., 2007. Adaptive Modeling, Adaptive Data Assimilation and Adaptive Sampling. Physica D 230, 172–196.

Oke, P. R., J. S. Allen, R. N. Miller, G. D. Egbert, and P. M. Kosro 2002. Assimilation of surface velocity data into a primitive equation coastal ocean model. *J. Geophys. Res.*, **107**(C9), 3122, doi:10.1029/2000JC000511, 2002.

Snyder, C., and F. Zhang, 2003. Assimilation of Simulated Doppler Radar Observations with an Ensemble Kalman Filter. Monthly Weather Review, 131, 1663–1677.

Torn, R., G. Hakim, and C. Snyder, 2006. Boundary Conditions for Limited-Area Ensemble Kalman Filters. Monthly Weather Review, 134 (9), 2490–2502 DOI: 10.1175/MWR3187.1

Wolfe, C. L., and R. M. Samelson, 2007. An efficient method for recovering Lyapunov vectors from singular vectors. *Tellus*, 59A, 355-366.